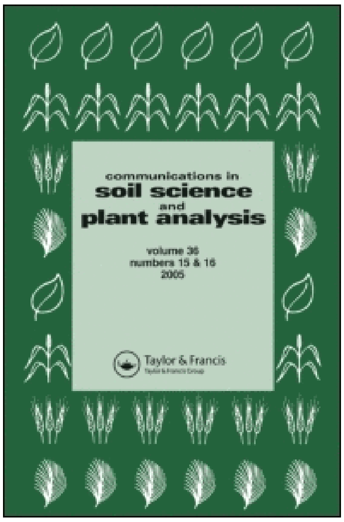

Communications in Soil Science and Plant Analysis
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597241

A Technique to Estimate Nitrate-Nitrogen Loss by Runoff and Leaching for Agricultural Land, Lancaster County, Nebraska

M. A. Elrashidi [a]; M. D. Mays [a]; S. D. Peaslee [a];D. G. Hooper [a]
[a] Soil Survey Laboratory, National Soil Survey Center, USDA/NRCS, Lincoln, Nebraska, USA

Online publication date: 28 September 2004

To cite this Article Elrashidi, M. A. , Mays, M. D. , Peaslee, S. D. andHooper, D. G.(2005) 'A Technique to Estimate Nitrate-Nitrogen Loss by Runoff and Leaching for Agricultural Land, Lancaster County, Nebraska', Communications in Soil Science and Plant Analysis, 35: 17, 2593 — 2615
To link to this Article: DOI: 10.1081/LCSS-200030396
URL: http://dx.doi.org/10.1081/LCSS-200030396

COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
Vol. 35, Nos. 17 & 18, pp. 2593–2615, 2004

A Technique to Estimate Nitrate–Nitrogen Loss by Runoff and Leaching for Agricultural Land, Lancaster County, Nebraska

M. A. Elrashidi,* M. D. Mays, S. D. Peaslee, and D. G. Hooper

Soil Survey Laboratory, National Soil Survey Center,
USDA/NRCS, Lincoln, Nebraska, USA

ABSTRACT

Nitrate-nitrogen (N) loss from agricultural land to natural water resources is an issue for both crop production and water quality. The objective of this study was to develop a technique to evaluate and map nitrate-N loss by surface runoff and subsurface leaching for agricultural land. The technique implemented water loss calculated by the National Resources Conservation Service (NRCS) runoff equation and a percolation model to predict nitrate-N loss for soils with different types of land cover. The technique was applied on agricultural land in Lancaster County, Nebraska, which covers 221,000 ha near the eastern edge of the Great Plains. The Soil Survey Report was used to identify 11 major soil series that comprise 83% of acreage in the county. Predicted nitrate runoff loss from soils

*Correspondence: M. A. Elrashidi, Soil Survey Laboratory, National Soil Survey Center, USDA/NRCS, 100 Centennial Mall North, Lincoln, NE 68508, USA; Fax: 402-437-5760; E-mail: moustafa.elrashidi@usda.gov.

DOI: 10.1081/LCSS-200030396
0010-3624 (Print); 1532-2416 (Online)

ranged from 0.84 to 6.20 kg/ha/y for fallow, 0.83 to 5.97 kg/ha/y for cropland, and 0.80 to 5.29 kg/ha/y for grassland. For most soils nitrate loss by leaching was greater than that by runoff. The average loss predicted by leaching was 8.75, 7.01, and 3.73 kg/ha/y for fallow, cropland, and grassland, respectively. Nitrate concentration predicted in runoff water from three crop-covered soils exceeded the threshold of 10 mg/L, while most soils generated leaching water with nitrate exceeding 10 mg/L. The county-level average of nitrate predicted in runoff (6.55 mg/L) and leaching water (11.8 mg/L) emphasized a need of nutrient management plan to reduce N loss from cropland. The Geographical Information Systems (GIS) were applied to map water loss and nitrate risk potential (NRP) for surface and groundwater contamination in the county.

Key Words: Groundwater quality; Nitrate loss; Nitrate Risk Potential; Subsurface leaching; Surface runoff; Water percolation.

INTRODUCTION

A comprehensive study by the Great Plains Agricultural Council[1] concluded that agricultural land is the largest contributor of nonpoint source pollution to natural water resources in the High Plains region and throughout the United States. Nitrate-N is the most commonly detected agricultural chemical in surface and groundwater. The U.S. Environmental Agency (USEPA)[2] estimated that more than 50% of the U.S. wells contain nitrate-N, with about 1.2% of community wells and 2.4% of rural wells having concentrations above the 10 mg/L health advisory threshold.

The U.S. Public Health Service, as well as the USEPA, has established 10 mg/L nitrate-N as the maximum contaminant limit (MCL) in drinking water for humans and animals.[2] Levels above 10 mg/L can lead to methemoglobinemia, or ‘‘blue baby’’ syndrome, which is caused by the reduction of oxygen carrying capacity of blood and can lead to brain damage and death.

In the early 1970s, the Central Platte Natural Resources District (NRD) of Nebraska sponsored a study of groundwater quality across the Central Platte valley. The results, published in 1974, indicated that approximately 20% of the Central Platte valley extending from Kearny in the central part to Columbus in the northeast corner had groundwater nitrate that exceeded 10 mg/L.[3]

Other studies on the Central Platte valley[4,5] identified commercial fertilizers applied to cropland as the major source of groundwater nitrate-N in Nebraska. The vertical transport rate of nitrate-N was 76 cm/y in the fine-textured vadose zone of eight irrigated research plots at the University of Nebraska South Central Research and Extension Center.[6] The authors concluded that precipitation, which annually amounts to 66 cm/y, appears to have been the driving force for the vertical nitrate-N transport.

Loss of water by runoff and leaching through the vadose zone are the major vehicles by which nitrate-N is transported from agricultural land into surface and groundwater.[7] Methods to evaluate nitrate-N loss can vary in complexity and scale from simple screening to complex models. The complex models usually predict annual loss of nitrate-N with a high degree of accuracy. However, such models require extensive input data and a high level of technical expertise, which limit their use. On the other hand, screening methods may generate inaccurate and misleading results.

The objectives of this study were (1) to develop a user-friendly technique that implements runoff and percolation water loss models to predict the most probable amount of nitrate-N loss by runoff and leaching from agricultural land; and (2) to determine and map the spatial distribution of nitrate risk potential (NRP) for surface and groundwater contamination in Lancaster County, Nebraska.

MATERIALS AND METHODS

Lancaster County

Lancaster County is in southeast Nebraska. It is rectangular in shape, extending about 58 km from north to south and 39 km from east to west. The county covers 221,072 ha, of which 1944 ha are areas of water larger than 16 ha. Lancaster County is near the eastern edge of the Great Plains. In general, the soils in the county are moderately well drained or well drained. The aspect is mostly northward and eastward to the Platte River through Salt Creek and its tributaries. The extreme southern and southeastern parts are drained by tributaries of the Big Blue and Nemaha Rivers. The highest elevation, about 462 m, is in the extreme northwestern part of the county about 8 km northwest of Agnew and in the extreme southwestern part about 6 km south of Kramer. The lowest elevation, 328 m, is in an area in the northeastern part where Salt Creek leaves the county.[8]

Most of agricultural land in Lancaster County is under cultivation. According to Nebraska Agricultural Statistics,[9] 82% of the area in farms is planted to cultivated crops. The largest area is in soybeans (55,000 ha) followed by corn (50,000 ha). Other cultivated crops include sorghum, wheat, oats, beans, sunflowers, sugarbeets, and alfalfa.

Soils Sampling

Soil associations on the general soil map in the Soil Survey Report of Lancaster County, Nebraska,[8] were used to determine the major soil series. The soil associations included 11 dominant soil series (Table 1). Recently, updated soil survey activities have split one of these soils (Sharpsburg) to three series (Tomek, Yutan, and Asksrben). The new classification, however, should not affect results given in this study. The total area of these 11 soil series is 183,000 ha which comprise 83% of acreage in the county.

The timing of soil sampling is very important and critical because of the high solubility and mobility of nitrate-N in soils. Also, the timing might be dependent on the objective of the study. Predicting an annual loss requires numerous soil samples throughout the year to determine a representative value for soil N concentration. This is a formidable task for practical and economic reasons. In this study, it was assumed that sampling of soils during the spring and prior to fertilizer application for the summer crop would provide a good estimate of the status of soil N. Accordingly, during March and April of 2001, 16 samples were collected from the top 30-cm layer for each major soil series.

To obtain statistically representative samples, we divided the county into four sections (northeast, northwest, southeast, and southwest). Detailed soil maps (map sheets) were used to identify the soil sampling location for each soil series. However, diagnostic soil tests were performed before sampling to determine that the site was a representative of the soil series being sampled. For each soil series, four soil samples were taken in each section. Thus, 44 soil samples were collected in each of the four sections, for a total of 176 soil samples. Representative soil samples, 2 kg, were taken from the top 30-cm layer. All soils sampling were completed before fertilizer application for the summer crop.

Soluble nitrate-N was extracted by 1.0 M KCl solution and measured colorimetrically by Lachet Autoanalyzer (LACHET Instruments, Milwaukee, WI).[10]

Table 1. Major soils in Lancaster County, Nebraska, their hydrologic soil group, curve number (CN), and liquid limit used to calculate runoff water for fallow, crop, and grass land cover.

Soil	Classification	Hydrologic group	Curve number (CN)			Liquid limit (mL/kg soil)
			Fallow	Crop	Grass	
Burchard	Fine-loamy, mixed, mesic Typic Argiudolls	B	86	80	69	425
Butler	Fine, montmorillonitic, mesic Abruptic Argiaquolls	D	94	90	84	300
Crete	Fine, montmorillonitic, mesic Pachic Argiustolls	C	91	87	79	388
Judson	Fine-silty, mixed, mesic Cumulic Hapludolls	B	86	80	69	378
Kennebec	Fine-silty, mixed, mesic Cumulic Hapludolls	B	86	80	69	350
Nodaway	Fine-silty, mixed, nonacid, mesic Mollic Udifluvents	B	86	80	69	300
Pawnee	Fine, montmori-llonitic, mesic Aquic Argiudolls	D	94	90	84	475
Sharpsburg	Fine, montmorillonitic, mesic Typic Argiudolls	B	91	87	79	450
Steinauer	Fine-loamy, mixed (calcareous), mesic Typic Udorthents	B	91	87	79	375
Wymore	Fine, montmorillonitic, mesic Aquic Argiudolls	D	94	90	84	465
Zook	Fine, montmorillonitic, mesic Cumilic Haplaquolls	C/D	93	89	82	438

Estimating Runoff and Leaching Water

Rainfall is the primary source of water that runs off the surface of small agricultural watersheds. The main factors affecting the volume of rainfall that runs off are the kind of soil and the type of vegetation in the watershed.[11] The runoff equation can be written as follows:

$$Q = (R - 0.2S)^2 \div (R + 0.8S) \tag{1}$$

where Q is runoff (inch), R is rainfall (inch), and S is potential maximum retention (inch) after runoff begins.

The potential maximum retention (S) can range from zero on a smooth and impervious surface to infinity in deep gravel. The S value is converted to a runoff curve number (CN), which is dependent on both the hydrologic soil group and type of land cover by the following equation:

$$\mathrm{CN} = 1000 \div (10 + S) \tag{2}$$

According to Eq. (2), the CN is 100 when S is zero and approaches zero as S approaches infinity. Runoff CNs can be any value from 0 to 100, but for practical applications are limited to a range of 40 to 98. Substituting Eq. (2) into Eq. 1 gives:

$$Q = \{R - [2(100 - \mathrm{CN})/\mathrm{CN}]\}^2 \div \{R + [8(100 - \mathrm{CN})/\mathrm{CN}]\} \tag{3}$$

The CNs for various hydrologic soil groups and types of land cover (Table 1) were developed by examining rainfall runoff data from small agricultural watersheds.[11] When a watershed has several soils and land covers, a representative CN for the entire watershed can be estimated by area weighting.

In this study, hydrologic groups of the 11 soils investigated were used to determine CNs for fallow, crop (cropland), and grass (grassland). Further, the annual rainfall at various soil locations were taken from the U.S. National Water and Climate Center.[12]

Soil Conservation Service's hydrologists[11] developed the runoff Eq. (3) to estimate runoff from small agricultural watersheds by a 24-h rainfall event. It was assumed the 24-h storm was an effective rainfall (R) that could generate runoff. In this study, however, the runoff equation was applied to estimate runoff by an annual rainfall. It was assumed 20% of an annual rainfall in Lancaster County (730 mm) would generate runoff. The effective rain (R) = (annual rainfall ÷ 5). Information reported in the average annual runoff in the United States was used, 1951–1980,[13] to derive that assumption. This approach has insignificant

MARCEL DEKKER, INC.
270 Madison Avenue, New York, New York 10016

effect on runoff value derived from the runoff Eq. (3) because of the similarity of the effective rain value (R) used in both cases. However, it enables us to predict runoff water for an annual rainfall rather than a storm event, which is desirable to the agricultural community.

For each soil, both the runoff CN and effective rainfall (R) values were applied in the runoff Eq. (3) to calculate the runoff (Q) for fallow, crop, and grass. Noteworthy, Eq. (3) calculated runoff values in inches. The Q values were converted to millimeters and are presented in Table 2.

In this study, the amount of water that leaches from soil is determined by a model developed by Williams and Kissel.[14] The authors used an equation of the form used to estimate surface runoff water [Eq. (3)] to develop their equation that predicts the percolation index (PI).

$$\mathrm{PI} = (P - 0.4r)^2/(P + 0.6r) \tag{4}$$

where PI is an estimate of average annual percolation in inches, P is the average annual rainfall in inches, and r is a retention parameter. The retention parameter (r) is related to a percolation curve number (PCN) by using the equation:

$$r = (1000/\mathrm{PCN}) - 10 \tag{5}$$

Table 2. Runoff and leaching water for different soils and land covers (mm/y) in Lancaster County, Nebraska.

Soil	Water loss by runoff			Water loss by leaching		
	Fallow	Crop	Grass	Fallow	Crop	Grass
	(mm/y)			(mm/y)		
Burchard	39	29	15	117	94	50
Butler	57	47	36	19	15	8
Crete	50	41	28	47	37	20
Judson	39	29	15	117	94	50
Kennebec	39	29	15	117	94	50
Nodaway	39	29	15	117	94	50
Pawnee	57	47	36	19	15	8
Sharpsburg	39	29	15	117	94	50
Steinauer	39	29	15	117	94	50
Wymore	57	47	36	19	15	8
Zook	54	45	33	32	25	14
Weighted average	47	37	24	74	59	31

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

The values of PCN are 28, 21, 17, and 15 for hydrologic soil groups A, B, C, and D, respectively.[14]

Another factor of considerable importance in estimating percolation is the seasonal rainfall distribution. Rainfall that occurs in the absence of crops is much more likely to percolate than growing season rainfall (i.e., spring and summer) because evapotranspiration is low during the fall and winter. Williams and Kissel[14] introduced the seasonal index (SI) to estimate the seasonal precipitation effects on percolation.

$$SI = (2\ PW/P)^{1/3} \tag{6}$$

where PW is the effective precipitation (rainfall occurs in the absence of crops), and P is the annual precipitation. The effective precipitation (PW) for cropland in Lancaster County was computed by summing the values for October through May. Assuming evapotranspiration was very low during the winter months, December, January, and February were used to calculate PW for grassland. For fallow, however, $PW = P$ because of the absence of any land cover throughout the entire year.

The leaching index (LI) was estimated by combining Eqs. (4) and (6) as follows:

$$LI = (PI)(SI) \tag{7}$$

For the 11 soils investigated, the amount of leaching water was calculated by using the LI for fallow (bare soil), cropland, and grassland, data are given in Table 2.

Agricultural area covered by each soil series varies greatly in Lancaster County. Thus, area-weighted average was calculated for runoff and leaching water loss and presented in Table 2.

Estimating Nitrate-Nitrogen Loss by Runoff and Leaching

Nutrients such as N, K, P, and other agricultural chemicals are released from a thin layer of surface soil that interacts with rainfall and runoff. In chemical transport models, the thickness of the interaction zone is determined by model calibration with experimental data, with depths ranging between 2.0 and 6.0 mm.[15] Frere et al.,[16] however, suggested an interaction zone of 10 mm, assuming that only a fraction of the chemical present in this depth interacts with rainfall water. In another study in this laboratory,[17] the fixed thickness of 10 mm was used to calculate P released by runoff for 24 U.S. benchmark soils.

In this study, an interaction zone of 10 mm was used to calculate the amount of nitrate-N released from surface soils by runoff. Also, it was assumed that during the runoff occurrence, water content in the surface 10-mm soil depth is at the liquid limit, the moisture content at which the soil passes from a plastic to a liquid state. Thus, during the runoff occurrence, the total amount of water (where nitrate-N in the 10-mm soil depth is dissolved) is the sum of water within the soil body (liquid limit) and that on the surface of soil (runoff). It was assumed that only nitrate-N in runoff water was removed and lost during the runoff occurrence. For the 11 soils investigated, amounts of nitrate-N loss by runoff were calculated (kg/ha/y) and are given in Table 3 and Fig. 1.

Hubbard et al.[18] and Lowrance[19] studied nitrate-N losses from a small watershed (0.34 ha) in south Georgia. They found that most of the nitrate-N losses were leached from the top 30-cm soil layer when 620 mm of natural rainfall followed fertilizer application. In this study, to calculate nitrate-N loss by leaching, it was assumed that (1) rainfall initiates downward movement of nitrate-N present in the top 30-cm soil depth, and (2) a LI equivalent to the annual rainfall in Lancaster County, (730 mm) can leach all nitrate-N present in the top 30-cm soil depth. Thus, as an example, a LI of 73 mm for a soil would result in downward movement of 10% of

Table 3. Nitrate nitrogen loss from surface soil by runoff and leaching (kg/ha/y) for major soils under fallow, crop, and grass cover in Lancaster County, Nebraska.

	Nitrate-N loss by runoff			Nitrate-N loss by leaching		
Soil	Fallow	Crop	Grass	Fallow	Crop	Grass
	(kg/ha/y)			(kg/ha/y)		
Burchard	5.41	5.19	4.54	29.51	23.65	12.59
Butler	2.66	2.63	2.57	2.19	1.76	0.94
Crete	3.30	3.24	3.08	6.97	5.59	2.97
Judson	6.20	5.97	5.29	33.39	26.76	14.24
Kennebec	2.14	2.06	1.84	11.41	9.14	4.87
Nodaway	2.23	2.16	1.95	11.72	9.39	5.00
Pawnee	5.50	5.40	5.20	4.69	3.75	2.00
Sharpsburg	1.57	1.50	1.30	8.62	6.91	3.68
Steinauer	1.69	1.62	1.43	9.08	7.28	3.88
Wymore	0.84	0.83	0.80	0.72	0.57	0.31
Zook	1.68	1.65	1.58	2.42	1.94	1.03
Weighted average	2.50	2.43	2.23	8.75	7.01	3.73

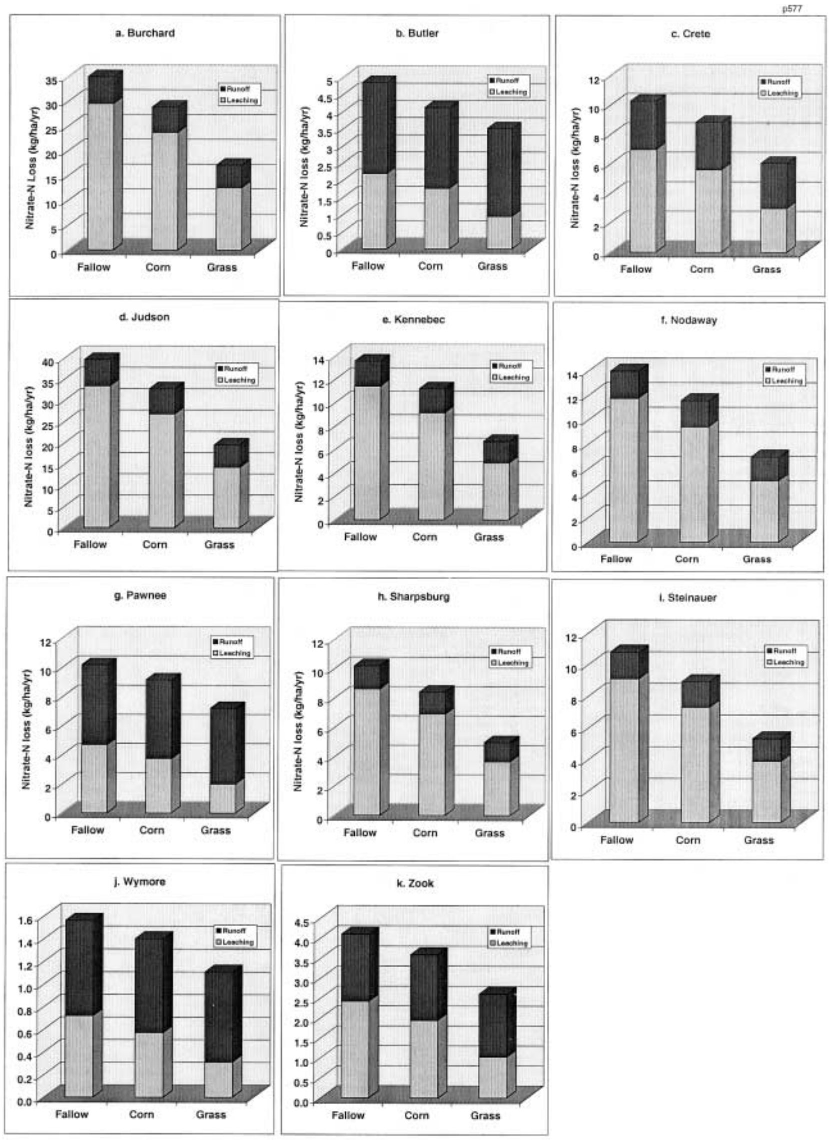

Figure 1. Nitrate-N loss by runoff and leaching (Kg/ha/y) for soils under fallow, corn, and grass in Lancaster County, Nebraska

nitrate-N present in the top 30-cm soil depth. For each soil, we used both the LI (mm/y) and concentration of nitrate-N (mg/kg soil) in the surface 30-cm soil depth to calculate nitrate-N loss by leaching for soil under fallow, crop, and grass. The nitrate-N leaching data for the major 11 soils in Lancaster County are given in Table 3 and Fig. 1.

Mapping Nitrate Risk Potential

Water loss and NRP maps for agricultural land in Lancaster County, were generated by GIS software. The GIS software used was ArcView 3.2a.[20] The input required to generate the map included spatial data layers (soil series and land cover) and the tabular data from the proposed technique (water loss and nitrate-N concentration in runoff and leaching water).

The principal spatial data layer used was the Soil Survey Geographic (SSURGO).[21] The National Land Cover[22] spatial layer was used to identify areas of cropland and grassland within the county. Other types of land cover, such as urban, forest, water, or marsh, were not mapped for NRP. The proposed technique calculated water loss and nitrate-N concentration in runoff and leaching water for soils under different types of land cover (crop and grass). Thus, GIS mapping of agricultural land in the county included data layers for soils and land cover in addition to water loss or nitrate-N. Maps illustrating the water loss by runoff and leaching (mm/y) for agricultural land in Lancaster County are given in Figs. 2 and 3, respectively.

Contemplating the MCL of 10 mg/L,[2] nitrate concentration (mg/L) either in runoff or leaching water was used to evaluate the NRP for cropland in Lancaster County. Five classes were designated to determine NRP as follows: low (<5 mg/L), medium (5 to 10 mg/L), medium–high (10 to 15 mg/L), high (15 to 20 mg/L), and very high (>20 mg/L). The GIS programs were implemented to develop digital maps illustrating NRP classes for agricultural land based on nitrate concentration in runoff (Fig. 4) or leaching (Fig. 5) water generated from different soils and land covers.

RESULTS AND DISCUSSION

Loss of Water

The loss of water by runoff and leaching for 11 major soils under fallow, crop, and grass in Lancaster County, is given in Table 2 and Figs. 2 and 3. In general, the effect of land cover on the

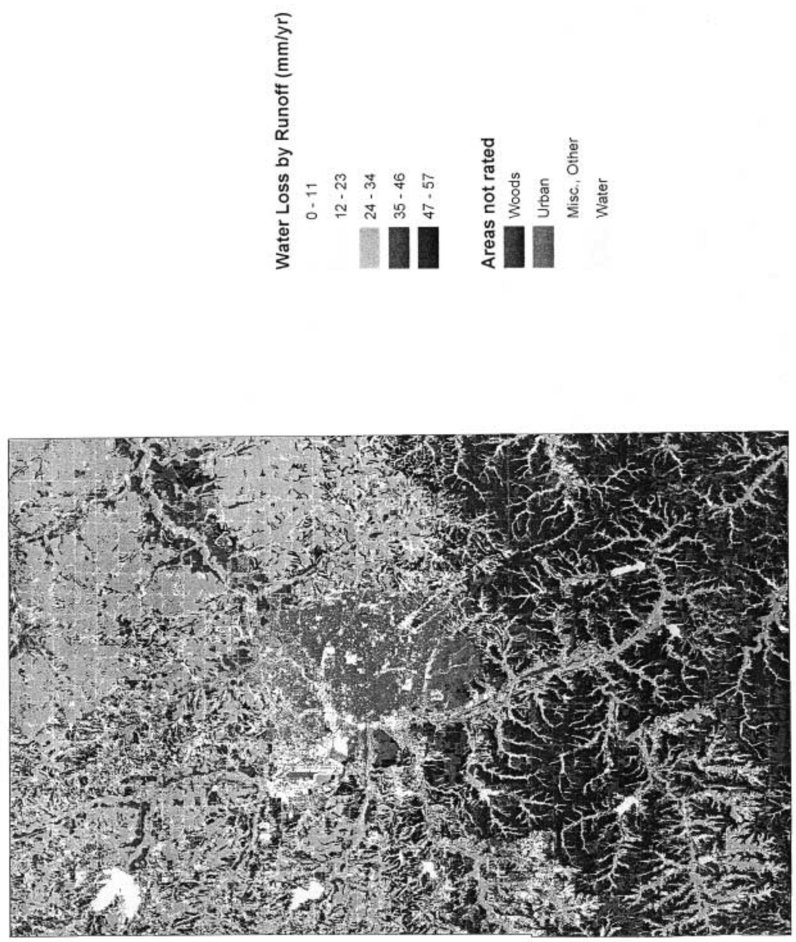

Figure 2. Water loss by runoff for agricultural land in Lancaster County, Nebraska.

magnitude of water loss by runoff from these soils followed this order: fallow > crop > grass. The runoff ranged between 39 and 57 mm/y for fallow, 29 and 47 mm/y for crop, and 15 and 36 mm/y for grass. These results accounted for an average of 6.44% of the annual rainfal in Lancaster County (730 mm) for fallow, 5.07% for cropland, and only 3.29% for grassland. These values appeared in agreement with average

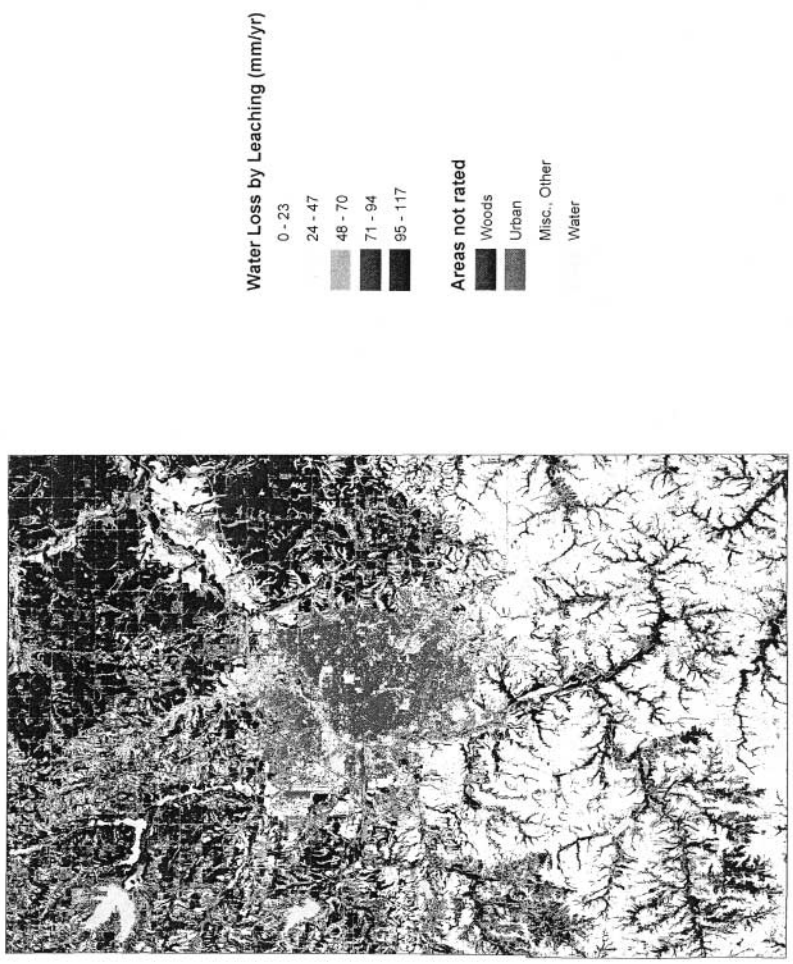

Figure 3. Water loss by leaching for agricultural land in Lancaster County, Nebraska.

annual runoff values reported by Gilbert el al.[13] for this area in Nebraska.

The effect of land cover on leaching water loss was similar to that obtained for runoff (fallow > crop > grass). Also, for most soils, the amount of water loss by leaching was greater than that for runoff.

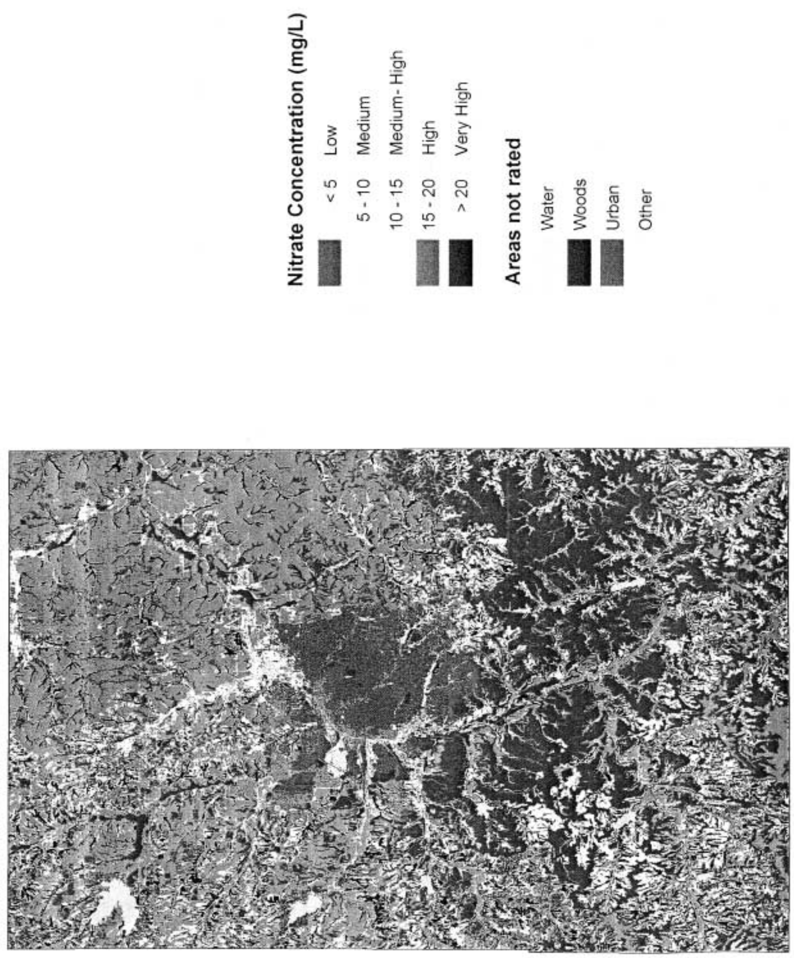

Figure 4. Risk potential for nitrate loss by runoff water for agricultural land in Lancaster County, Nebraska.

The water loss by leaching ranged from 19 to 117 mm/y for fallow, 15 to 94 mm/y for cropland, and 8 to 50 mm/y for grassland. The average amount of water that leached accounted for 10.1% of the annual rainfall for fallow, 8.01% for cropland, and 4.25% for grassland.

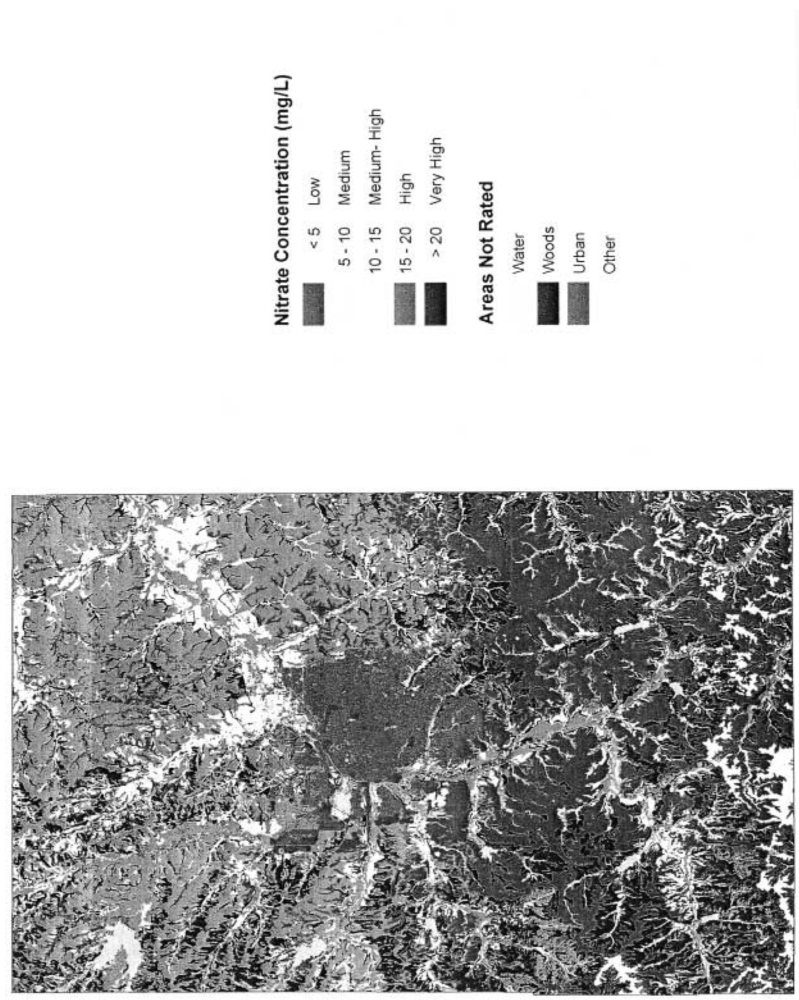

Figure 5. Risk potential for nitrate loss by leaching for agricultural land in Lancaster County, Nebraska.

Szilagyi et al.[23] estimated the long-term mean base recharge to groundwater in Nebraska with the help of a water balance and automated base flow separation technique. The base recharge to groundwater was derived by the product of estimated long-term mean annual runoff (the difference between precipitation and evapotranspiration) and the base flow index obtained at the U. S. Geological Survey's gaging stations in Nebraska. The average annual base recharge for the state of Nebraska was 48 mm, ranging from 3 to 14 mm near the border with Colorado to a high of 120–140 mm in the southeastern corner. These values of base recharge to groundwater in Nebraska appears to agree with our data on water loss by leaching for agricultural land in Lancaster County near the southeastern corner of the state.

Loss of Nitrate–Nitrogen

The loss of nitrate-N by runoff and leaching (kg/ha/y) for major soils under fallow, crop, and grass in Lancaster County are given in Table 3 and Fig. 1. In general, the effect of land cover on the magnitude of nitrate-N loss by runoff from all soils followed this order: fallow > crop > grass. For soils under fallow, nitrate-N loss by runoff ranged between 0.84 and 6.20 kg/ha/y with an average of 2.50 kg/ha/y. The soils with crop cover showed slightly lower values for nitrate-N loss by runoff ranging between 0.83 and 5.97 kg/ha/y with an average of 2.43 kg/ha/y. Unexpectedly, continuous grass cover during the entire year appeared to have only a slight reducing effect on the nitrate-N loss by runoff. The amount of nitrate-N loss for 11 soils under grass ranged from 0.80 to 5.29 kg/ha/y with an average of 2.23 kg/ha/y.

Similar runoff losses of nitrate-N were reported by Soileau et al.[24] for cotton grown in a small watershed (4 ha) in Alabama during three years of conventional tillage followed by three years of conservation tillage. The annual runoff losses of nitrate-N ranged from 1.0 to 6.6 kg/ha for conventional tillage, and 2.8 to 5.8 kg/ha for conservation tillage.

For 110 counties in the High Plains region, Wu et al.[25] used five categories to evaluate N loss by runoff: low (<1.68 kg/ha), medium-low (1.68 to 3.36 kg/ha), medium (3.36 to 5.04 kg/ha), medium-high (5.04 to 6.72 kg/ha), and high (>6.72 kg/ha). The ranges were determined so that the 110 county-level averages of N runoff (4.71 kg/ha) falls in the medium range. Therefore, these categories may only be used to compare N loss across the High Plains region.

These categories were used to compare nitrate-N loss by runoff for major soils in Lancaster County with N loss across the High Plains. For soils under fallow and crop, three soils were categorized at medium high, five soils at medium low, while three soils were classified at low. The county-level average for soils under fallow and crop cover was classified at medium low. For soils under grass cover, the nitrate-N loss by runoff was relatively lower than either fallow or crop. Three soils were classified at medium and eight soils were at medium low to low, while the county-level average was within the medium-low range.

For most soils, irrespective of land cover, the results indicated that nitrate-N loss by leaching was greater than that by runoff. For the 11 soils, the average loss by leaching was 8.75 kg/ha/y for fallow, 7.01 kg/ha/y for cropland, and 3.73 kg/ha/y for grassland. Lowrance[19] determined nitrate-N losses from a cropping system with summer row crops and winter cover crops during a period of four years to find that average loss of 36.5 kg/ha/y from subsurface leaching and 2.7 kg/ha/y from surface runoff. Hubbard et al.[18] also found that intensive rainfall shortly after fertilizer application resulted in the greatest losses of nitrate-N. Most of the losses of nitrate-N were from subsurface leaching rather than from surface runoff.

In this study, for soils under fallow, nitrate-N loss by leaching fluctuated widely from 0.72 to 33.4 kg/ha/y. Relatively lower values were calculated for soils with crop where nitrate-N loss ranged between 0.57 and 26.8 kg/ha/y. The least nitrate-N loss values were predicted for grassland, where it ranged from 0.94 to 14.24 kg/ha/y.

With respect to nitrate-N leaching losses, Wu et al.[25] used the following categories to evaluate N loss for 110 counties in the High Plains region. Low (<1.12 kg/ha), medium low (1.12 to 2.24 kg/ha), medium (2.24 to 3.36 kg/ha), medium high (3.36 to 4.48 kg/ha), and high (>4.48 kg/ha).By comparing nitrate-N losses by leaching in Lancaster County with those across the High Plains, it was found that eight soils under fallow and seven soils with crop cover should be considered at the high-loss category. Other soils under fallow and crop cover ranged between low and medium. For grassland, six soils were at the medium-high and high range, while the other five soils were within the medium and low range.

Wu et al.[25] found that out of the 110 counties investigated in the High Plains region, 32 counties were in the high N leaching loss category and the majority of these counties were located in the northern areas of the High Plains region. In an earlier study on the High Plains region, Nielsen and Lee[26] identified 58 of the 110 counties investigated as having potential for groundwater contamination from nitrate sources (51 counties belonged to medium category, while the other seven counties fell into high category).

Several studies in the north central region of the United States[28] reported greater amounts of nitrate-N leaching losses than those found in this study. Timmons and Dylla[29] reported an average annual nitrate-N leaching loss ranged from 29 to 112 kg/ha for a corn field

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

during a five-year period in central Minnesota. In southwest Michigan, Rasse et al.[30] found that the application of 101 and 202 kg N/ha to a maize field during a five-year period generated an average nitrate-N leaching loss of 26 and 60 kg/ha/y, respectively, during the last two years of treatment. These large leaching losses in the north-central region might be a result of higher annual precipitation, coarser soil texture, and a faster rate of water infiltration. Moreover, studies in the north region were conducted on soils following application of N fertilizers. In this study, however, precautions were undertaken to avoid soil sampling from fertilized fields.

Nitrate Risk Potential

No attempt was made to relate the runoff and leaching categories, used to evaluate the predicted amount of nitrate-N loss for soils, to the potential risk for surface or groundwater contamination. However, the nitrate and water loss data was used to calculate the concentration of nitrate-N in surface runoff and subsurface leaching water for different soils and land covers in Lancaster County. Most agricultural land in the county is cultivated with crop, while only a small portion is in grass.[8] Table 4 shows only calculated nitrate concentration data for cropland.

As mentioned above, five classes were suggested to evaluate NRP for runoff and leaching water generated from agricultural land in Lancaster County. Calculated nitrate concentration data for different soils and land covers were used to develop the NRP maps for agricultural land in the county. Figures 4 and 5 show the NRP category in which each soil falls for surface runoff and for subsurface leaching water, respectively. Soils with reddish or dark colors have the highest potential for nitrate contamination of surface waters (Fig. 4) and groundwater (Fig. 5).

The maps (Figs. 4 and 5) show that soils generating runoff and leachate of nitrate concentration exceeding the MCL of 10 mg/L are scattered all over the county. Also, they show that the risk from nitrate loss by leaching is much higher than from runoff. Moreover, agricultural land in the southern and southwestern area appear to contribute relatively more risk to groundwater contamination than the rest of the county. This could be attributed to the concentration of corn fields in these areas. Corn plants usually require a heavy application of N fertilizers.

The data in Table 4 also show that approximately 176 million cubic meter of water and 1762 metric tons of nitrate-N were lost annually from cropland in Lancaster County. Most of these nitrate losses (1282 metric

Table 4. Predicted nitrate concentration in runoff and leaching water (mg/L) and nitrate risk potential[a] (NRP) for soils with crop cover in Lancaster County, Nebraska.

Soil	Area (hectar)	Water loss (million m^3/y)		Nitrate-N loss (Mg/y)		Nitrate-N (mg/L)		Nitrate risk potential[a]	
		Runoff	Leaching	Runoff	Leaching	Runoff	Leaching	Runoff	Leaching
Burchard	7960	2.34	7.45	41.31	188.25	17.68	25.28	H	VH
Butler	1620	0.77	0.24	4.26	2.85	5.54	11.71	M	MH
Crete	8020	3.32	3.00	25.98	44.83	7.83	14.94	M	MH
Judson	11932	3.50	11.16	71.23	319.30	20.34	28.60	VH	VH
Kennebec	9160	2.69	8.57	18.87	83.72	7.02	9.77	M	M
Nodaway	13080	3.84	12.24	28.25	122.82	7.36	10.04	M	MH
Pawnee	22760	10.80	3.41	122.90	85.35	11.38	25.00	MH	VH
Sharpsburg	52908	15.34	49.51	79.36	365.59	5.17	7.38	M	M
Steinauer	5060	1.47	4.73	8.20	36.84	5.59	7.78	M	M
Wymore	47780	22.67	7.18	39.66	27.23	1.75	3.79	L	L
Zook	2540	1.15	0.65	4.19	4.93	3.64	7.63	L	M
All	182820	67.83	108.23	444.25	1281.57	6.55	11.84	M	MH

[a]NRP categories: L (low), M (medium), MH (medium high), H (high), and VH (very high).

tons) were attributed to subsurface leaching. The nitrate-N concentration in runoff water generated from three soils (Judson, Burchard, and Pawnee) exceeded the established MCL of 10 mg/L. The NPR for the three soils was classified at very high, high, and medium high, respectively, while the potential risk for the other eight soils was classified at medium and low range. The county-level average of nitrate-N concentration in runoff water generated from cropland (6.55 mg/L) was below the MCL and the NRP was at the medium range.

On the other hand, most crop-covered soils in the county (Burchard, Butler, Crete, Judson, Nodaway, and Pawnee) generated subsurface leaching water with nitrate-N concentration exceeding the MCL of 10 mg/L. The NRP for these soils ranged between medium high to very high. The county-level average of nitrate-N concentration in subsurface leaching water (11.84 mg/L) generated from cropland might raise some concern for groundwater contamination.

SUMMARY AND CONCLUSIONS

A technique was proposed to estimate nitrate-N loss by runoff and leaching for agricultural land. The technique can be applied on a small agricultural watershed (20 to 40 ha) or on large areas of agricultural land that may include several-hundred thousands of hectares (county). Predicted nitrate quantity and concentration in runoff and leaching water can be used to evaluate and map potential risk for surface and groundwater contamination. To apply the technique, results on nitrate-N concentration in surface soils are required along with climate and soil information data. This information (i.e., precipitation, soil series, land covers, acreage, hydrologic soil group, curve number, and soil properties) can be found in the Soil Survey database. The following paragraph outlines the proposed technique.

The process begins by using the soil survey report to identify major soil series and its geographical locations, so representative soil samples can be collected and analyzed for soluble nitrate-N. Data on precipitation and hydrologic soil groups can be applied (runoff equation and percolation model) to predict the depth of runoff and leaching water for different soils and land covers. Predicted water loss is used to calculate nitrate loss and concentration in runoff and leaching water for different soils and land covers. Then, nitrate concentration is used to designate NRP for runoff and leaching water generated from different soils. Finally, GIS programs can be run to map NRP for surface and groundwater contamination.

Application of the technique indicated that runoff water generated from agricultural land in Lancaster County had a low risk to surface water contamination. Most soils with crop cover, however, could generate leaching water with nitrate exceeding the MCL, which might pose a problem for groundwater quality. Appropriate nutrient management planning should be considered for cultivated fields to reduce N loss from soils by leaching.

ACKNOWLEDGMENTS

The authors are grateful to Robert Ahrens for his support during the course of this study. Thanks to Robert Grossman, Cathy Seybold, Warren Lynn, and Mike Wilson for their invaluable suggestions and constructive criticism. We also thank Patty Jones, Tammy Umholtz, Tom Zimmer, Chris Lee, Pam VanNeste, and Crystal Schaecher for the technical assistance.

REFERENCES

1. Great Plains Agricultural Council, Water Quality Task Force. *Agricultural and Water Quality in the Great Plains: Status and Recommendations*; The Texas Agricultural Experimental Station MP-1738, The Texas A&M University System: College Station, TX, 1992.
2. USEPA. *Managing Nonpoint Source Pollution*, Final Report to Congress on Section 319 of the Clean Water Act; USEPA: Washington, DC, 1992; EPA-506/9-90.
3. Bishop, R. A local agency's approach to solving the difficult problem of nitrate in the groundwater. J. Soil Water Conserv. **1994**, *49*, 82–84.
4. Gormly, J.R.; Spalding, R.F. Sources and concentrations of nitrate-nitrogen in groundwater of the Central Platte Region, Nebraska. Ground Water **1979**, *17*, 291–301.
5. Schepers, J.S.; Moravek, M.G.; Alberts, E.E.; Frank, K.D. Maize production impacts on groundwater quality. J. Environ. Qual. **1991**, *20*, 12–16.
6. Bobier, M.W.; Frank, K.D.; Spalding, R.F. Nitrate-N movement in a fine textured vadose zone. J. Soil Water Conserv. **1993**, *48*, 350–354.
7. Allison, F.E. The fate of nitrogen. Adv. Agron. **1966**, *18*, 219–258.

8. Brown, L.E.; Quandt, L.; Scheinost, S.; Wilson, J.; Witte, D.; Hartung, S. *Soil Survey of Lancaster County*, *Nebraska*; U.S. Dept. of Agriculture, Soil Conservation Service: Washington, DC, 1980; 1–174.
9. USDA. *Nebraska Agricultural County Profiles*; U.S. Dept. of Agriculture, National Agricultural Statistics Service: Washington, DC, 2002.
10. USDA/NRCS. *Soil Survey Laboratory Methods Manual*, Version No. 3; USDA-NRCS: Washington, DC, 1996; Soil Surv. Investigations Rept. No. 42.
11. USDA/SCS. *National Engineering Field Manual: Estimating Runoff and Peak Discharges*; USDA-NRCS: Washington, DC, 1991; Chap. 2, 1–19.
12. U.S. National Water and Climate Center. 2003. http://www.WCC.NRCS.gov/water/W_CLIM.html.
13. Gilbert, W.A.; Graczyk, D.J.; Krug, W.R. *Average Annual Runoff in the United States, 1951–1980: Hydrologic Investigations*; U.S. Geological Survey: Reston, VA, 1987; National Atlas HA-710.
14. Williams, J.R.; Kissel, D.E. Water percolation: an indicator of nitrogen-leaching potential. In *Managing Nitrogen for Groundwater Quality and Farm Profitability*; Follett, R.F., Keeney, D.R., Cruse, R.M., Eds.; Soil Sci. Soc. Am.: Madison, WI, 1991; Chap. 4, 59–83.
15. Donigian, A.S., Jr.; Beyerlein, D.C.; Davis, H.H.; Crawford, N.H. *Agricultural Runoff Management* (*ARM*) *Model*, *Version II: Refinement and Testing*; Environ. Res. Lab., U.S. Environmental Protection Agency: Athens, GA, 1977; EPA 600/3-77-098.
16. Frere, M.R.; Ross, J.D.; Lane, L.J. The nutrient sub-model. In *CREAMS: A Field Scale Model for Chemicals*, *Runoff and Erosion from Agricultural Management Systems*; Knisel, W.G., Ed.; USDA-SEA-Conservation: Washington, DC, 1980; Res. Rep. No. 26, Chap. 4, 1, 65–86.
17. Elrashidi, M.A.; Mays, M.D.; Jones, P.E. A technique to estimate release characteristics and runoff phosphorus for agricultural land. Commun. Soil Sci. Plant Anal. **2003**, *34*, 1759–1790.
18. Hubbard, R.K.; Leonard, R.A.; Johnson, A.W. Nitrate transport on a sandy coastal plain soil underlain by plinthite. Trans. ASAE **1991**, *34*, 802–808.
19. Lowrance, R. Nitrogen outputs from a field-size agricultural watershed. J. Environ. Qual. **1992**, *21*, 602–607.
20. ESRI (Environmental Systems Research Institute), 1999. http://www.esri.com.

21. USDA/NRCS. Soil Survey Geographic (SSURGO) Database for Lancaster County, Nebraska, 1999. http://www.ftw.nrcs.usda.gov/ssur_data.html.
22. NLCD. National Land Cover Data for Nebraska, Version 05-07-00 Nominal Thematic Mapper, 1992. http://landcover.usgs.gov/natllandcover.html.
23. Szilagyi, J.; Harvey, F.E.; Ayers, J.F. Recharge maps to assist management of groundwater and surface water: resource notes. Inst. Agric. Natural. Resour., Univ. Nebraska-Lincoln **2002**, *16*, 17–18.
24. Soileau, J.M.; Touchton, J.T.; Hajek, B.F.; Yoo, K.H. Sediment, nitrogen, and phosphorus runoff with conventional- and conservation-tillage cotton in a small watershed. J. Soil Water Conserv. **1994**, *49*, 82–89.
25. Wu, J.J.; Bernardo, D.J.; Mapp, H.P.; Geleta, S.; Teague, M.L.; Watkins, K.B.; Sabbagh, G.J.; Elliott, R.L.; Stone, J.F. An evaluation of nitrogen runoff and leaching potential in the High Plains. J. Soil Water Conserv. **1997**, *52*, 73–80.
26. Nielsen, E.G.; Lee, L.K. *The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals: A National Perspective*; U.S. Department of Agriculture, Economic Research Services: Washington, DC, 1987; Agric. Econ. Rep. No. 576.
27. Olsen, R.J.; Hensler, R.F.; Attoe, O.J.; Witzel, S.A.; Peterson, L.A. Fertilizer nitrogen and crop rotation in relation to movement of nitrate nitrogen through soil profiles. Soil Sci. Soc. Am. Proc. **1970**, *34*, 448–452.
28. Gast, R.G.; Nelson, W.W.; Randall, G.W. Nitrate accumulation in soils and loss in tile drainage following nitrogen application to continuous corn. J. Environ. Qual. **1978**, *7*, 258–262.
29. Timmons, D.R.; Dylla, A.S. Nitrogen leaching as influenced by nitrogen management and supplemental irrigation level. J. Environ. Qual. **1981**, *10*, 421–426.
30. Rasse, D.P.; Ritchie, J.T.; Peterson, W.R.; Loudon, T.L.; Martin, E.C. Nitrogen management impacts on yield and nitrate leaching in inbred maize systems. J. Environ. Qual. **1999**, *28*, 1365–1371.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016